Draft version: Not yet approved by the European Commission

# Cover Delivery Report

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| **Title of the Deliverable:** | **Third annual update of the factsheets with a summary on the performance of the demonstration plants (for website)** |
| **WP Title and Number:** | **WP1, D1.8** |
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*This project has received funding from the European Union's H2020 research and innovation programme under the grant agreement No: 730400. SYSTEMIC started 1 June 2017 and will continue for 4 years.*

*This deliverable contains the factsheets of SYSTEMIC's demonstration plant:*

1) *Groot Zevert Vergisting*
2) *AmPower*
3) *Aqua&Sole*
4) *Benas*

*The factsheet of the fifth demonstration plant (Friday's in Kent) has not been updated because SYSTEMIC has decided to change Friday's for another plant named Waterleau (Ieper) because of serious delays in the construction of the AD plant at Friday's. At the moment of writing, this change in demonstration plant was not yet formally approved by the EC and hence, the factsheet of the fifth demonstration plant was therefore not updated and not included in this deliverable.*

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# Groot Zevert Vergisting, Beltrum (Netherlands)

## A short introduction to GZV

Groot Zevert Vergisting (GZV; Figure 1), located in Beltrum, The Netherlands, started its biogas production in 2004. The company can process 135 kilotonnes (kt) of feedstock through mesophilic digestion per year. In 2019, GZV started with the production of biobased fertilisers and clean water from digestate. The aim is to offer a sustainable solution to the manure surplus in their region.

*Table 1. Technical information of the biogas plant.*

| Characteristics | |
|---|---|
| Year of construction | 2004 |
| Maximum power output | 6.5 MWe |
| Digester volume | 15 000 m$^3$ |
| Digestion type | Mesophilic digestion |
| Nutrient recovery facilities | GENIUS: decanter centrifuges, microfiltration, reverse osmosis<br>RePeat: acidification and phosphorous precipitation |

## Drivers for Nutrient Recycling

In the Netherlands, manure production by livestock is greater than the amount that legally can be applied on agricultural land. Maximum application standard for both nitrogen (N) and phosphorus (P) determine the amounts of manure that can be applied. The surplus of pig manure, about 30% of the produced amount, is exported, mostly to Germany. The transport of large volumes of manure over distances of 200–400 km is costly. As a consequence, farmers are faced with high costs for manure disposal (€ 25,- per ton pig manure).

*Figure 1. Groot Zevert Vergisting in Beltrum, The Netherlands.*

As a solution to the manure surplus in the region, GZV decided to invest in nutrient recovery technologies to convert digestate into valuable biobased fertilisers:

- Nitrogen potassium (NK) concentrate to be used within the region;
- Cleaned water which is allowed to be discharged in a nearby stream;
- Organic soil improver with a low nutrient content;
- Secondary P resource to be used as ingredient for the production of fertilisers by fertilisers producing companies.

These biobased fertilisers can be used within the region and some of them can be exported over long distances against low costs as their volumes are reduced by processing. The processing is therefore expected to generate substantial costs savings.

## Feedstocks

In 2018 GZV's co-digestion plant has increased its treatment capacity from 102 to 135 kt feedstock per year, but not all capacity was used (Table 2). Animal manure was the major substrate (about 80% of total feedstock) but the co-substrates are responsible for a relatively large part of the biogas production, about 75% of it in 2019. Pig manure was collected from about 55 pig farms within a distance of 25 km of the plant.

*Table 2. Origin of GVZ's digester feedstock (2018–2019).*

| Type | Origin | Mass (2018) | Mass (2019) |
|---|---|---|---|
| **Manure** | Pig slurry | 74 kt | 75 kt |
| | Dairy cattle slurry | 5 kt | 5 kt |
| | Slaughterhouse manure | 12 kt | 10 kt |
| **Co-substrates** | Waste dairy and feed industry | 21 kt | 18 |
| | Glycerin | 3 kt | 4 kt |
| **Total** | | **115 kt** | **112 kt** |

# Groot Zevert Vergisting, Beltrum (Netherlands)

## Biogas production

The yearly biogas production is roughly 9 Mio $Nm^3$ (Table 3). About 68% of the produced biogas is transported through a 5 km-long pipeline to a dairy factory (Friesland-Campina). The remaining 32% of the produced biogas is on-site converted into electric power and heat.

*Table 3. Yearly biogas production in 2019 and average composition before desulphurisation.*

| Component | 2019 |
|---|---|
| $CH_4$ (% v/v) | 55 |
| $CO_2$ (% v/v) | 43 |
| $H_2S$ (ppm) | 1000–2000 |
| $O_2$ (% v/v) | 0.2 |
| Total biogas production (Mio $Nm^3$) | 9 |
| Biogas per tonne of feedstock ($Nm^3$/t) | 78 |

## Nutrient Recovery and Reuse (NRR) Technologies

GZV follows the concept of a Green Mineral Mining Centre. Digestate is separated into a solid and a liquid fraction by a decanter centrifuge. The nutrient recovery process consist of two independent installations, GENIUS for the processing of the liquid fraction and RePeat for the processing of the solid fraction.

The RePeat process separates the P from the organic matter through extraction with water and sulphuric acid followed by precipitation and recovery of phosphorus through addition of $Mg(OH)_2$ or $Ca(OH)_2$. The solid fraction is treated in two sequential leaching steps during which 70–90% of the P is removed. What remains is an organic soil improver with a low P content. Part of the sulphate, added as sulphuric acid, precipitates with calcium as gypsum. This gypsum is either recovered together with the P fertiliser or as a separate organic gypsum-rich sludge that can be used as fertiliser. Water is continuously reused within the process. Hence, creation of an additional waste stream is prevented.

In the GENIUS process, the liquid fraction is further processed into a nitrogen-potassium (NK) concentrate and clean water through a combination of dissolved air flotation (DAF), micro filtration (MF) and reverse osmosis (RO). The water is being treated by an ion exchanger (IonX) to comply with standards for discharge on surface water.

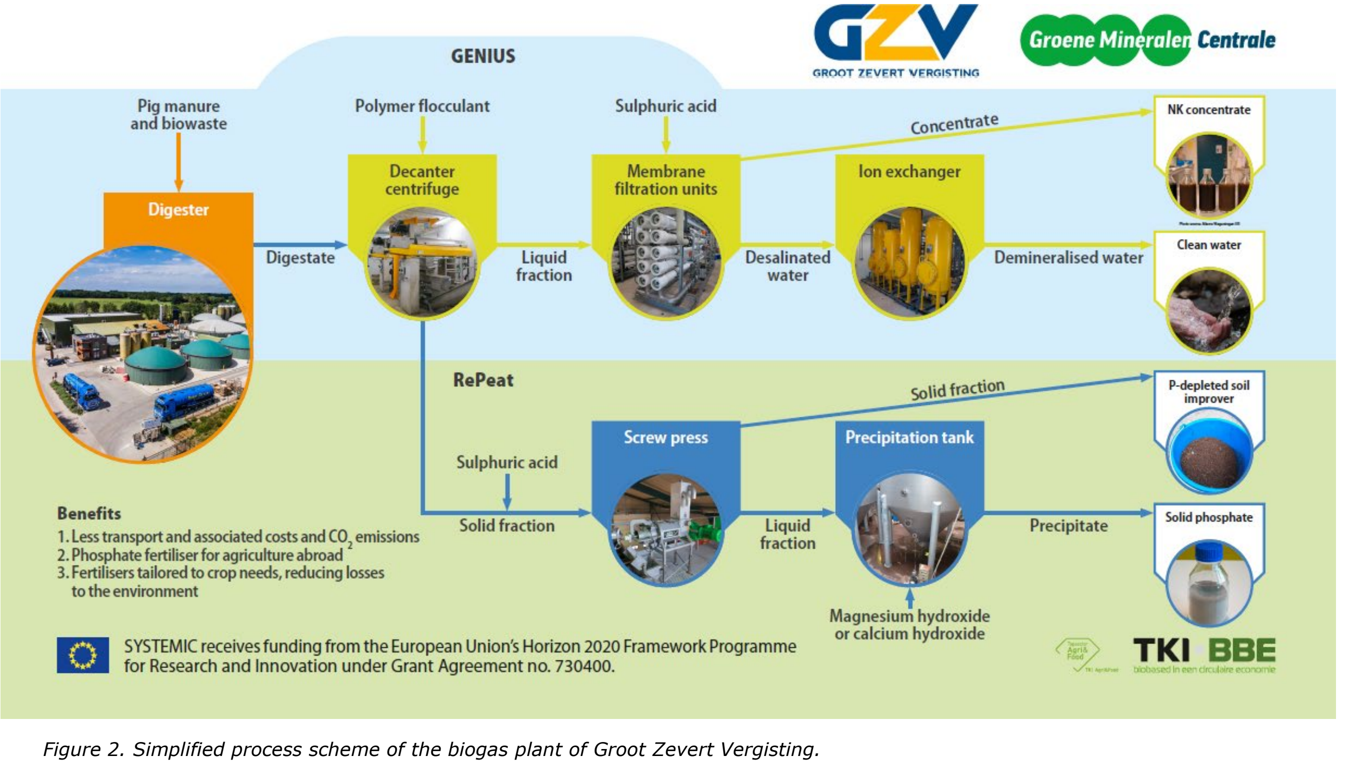


*Figure 2. Simplified process scheme of the biogas plant of Groot Zevert Vergisting.*

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# Groot Zevert Vergisting, Beltrum (Netherlands)

## Status of construction

Construction of the RePeat installation was finalized early 2020 and since then, the installation has been in use for eight hours per day. The RePeat installation has a treatment capacity of 2 tonnes of solid fraction per hour. The installation includes three screw presses, multiple mixing and buffering tanks, a lamella clarifier, a 60 $m^3$ precipitation tank and a settling tank. In 2020, GZV will further focus on further optimization of the process and the technology. Focus points are an improved dewatering of the precipitate and a reduction of the chemical consumption rate. The GENIUS installation has been in operation since January 2019. In 2019, GZV and Nijhuis Industries have further improved the efficiency of the installation. The performance of both installations is monitored by Wageningen Environmental Research.

## Products and market

The NK concentrate has an N content of about 6.9 g $kg^{-1}$ of which >90% is N-$NH_4$. The NK concentrate is used as an alternative for synthetic fertilisers on arable land and grass land in the region of the plant. About 20–30% of the digestate is converted into clean water that can be discharged on surface water. The solid fraction was shipped to Germany in 2019 but will be processed into a low-P organic soil improver and P fertiliser from 2020 onwards. The low-P organic soil improver will be used on sandy soils in the region of the plant. Besides, GZV investigates the opportunities of it to become an alternative for peat in potting soil. The P precipitate is yet recovered as a sludge which needs a further dewatering and drying step after which it can be used as a raw material in the fertiliser industry.

*Table 4. Average composition of the recovered products in 2019 (GENIUS, n:10) and March 2020 (RePeat, n:1).*

| | | GENIUS | | | RePeat | |
|---|---|---|---|---|---|---|
| | Ingoing Digestate | NK concentrate | Solid fraction of digestate | Clean water | Low-P organic soil improver | P precipitate[a] |
| Dry matter (g $kg^{-1}$) | 84 | 43 | 306 | | 368 | 128 |
| Organic Matter (g $kg^{-1}$) | 60 | 16 | 232 | <d.l. | 330 | 66 |
| N-total (g $kg^{-1}$) | 7.2 | 6.9 | 12.1 | 0.003 | 6.5 | 5.4 |
| N-$NH_4$ (g $kg^{-1}$) | | | | | | |
| P-total (g $kg^{-1}$) | 1.7 | 0.16 | 8.9 | <0.0001 | 3.0 | 6.5 |
| K-total (g $kg^{-1}$) | 4.2 | 8.2 | 4.4 | <0.0004 | | 1.25 |
| S-total (g $kg^{-1}$) | 0.8 | 4.8 | 2.2 | 0.0004 | 4.8 | 8.5 |

[a] *Phosphorous precipitate before thermal drying.*

## Economic benefits

Long distance transport of digestate or solid fraction of digestate to Germany is costly. Implementation of the GENIUS and RePeat process enables GZV to sell their products to farmers in the region of the plant, thereby saving costs for transport.

## Sustainability goals

- Balanced fertilisation with products from co-digested pig slurry.
- Replacement of synthetic N fertiliser by biobased liquid fertiliser containing 10–15 g $L^{-1}$ N-$NH_4$ and 10–15 g $L^{-1}$ $K_2O$.
- Recovery of the non-renewable element P in a valuable concentrated product to be used elsewhere, as fertiliser or secondary raw material for fertiliser producing industries.
- A substantial decrease in $CO_2$ emissions associated with transport.

## Monitoring data (mass flow)

Mass (Figure 3) and nutrient (Figure 4) balances were derived for the GENIUS installation at GZV over a period of four months. The aim was to evaluate the overall performance and efficiencies of separation processes. The first decanter centrifuge recovered 65% of the P from the digestate into a solid fraction with a dry matter content of 30%. Prior to the first decanter, $MgCl_2$ was dosed to improve the removal of P from the digestate. The first and second decanter, together removed 90% of the P from the digestate. The solid fraction of the second decanter is fed to the post-digester. The microfiltration unit effectively removed most of the remaining P as well as organic N. As a drawback, the microfiltration unit produced a large amount of sludge most of which was disposed of as manure. The remaining liquid fraction after microfiltration was concentrated by a factor 2.1 by the two subsequent RO units. After polishing by the IonX clean water remains, of which nearly half was reused within the process. In terms of end products, every 100 t of digestate was processed into 16 t of solid fraction, 37 t of sludge (trucked off-site), 27 t of NK concentrate and 14 t of clean water (discharge/evaporation). In 2020, GZV will further optimize the system in order to minimize the amount of sludge from microfiltration that needs to be trucked off-site and to increase the percentage of clean water produced. Furthermore, GZV will focus on improving the quality of the products from the RePeat installation.

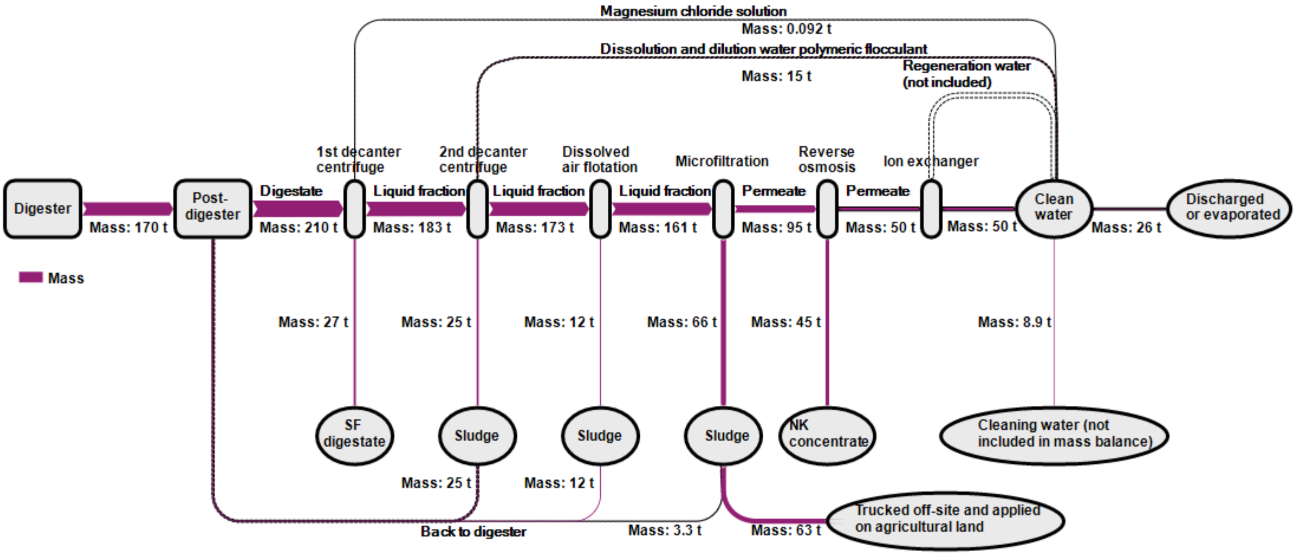


*Figure 3 Mass flows at Groot Zevert Vergisting for period October 2019–January 2020 (n: 4). Values expressed in tonnes per day (t $d^{-1}$).*

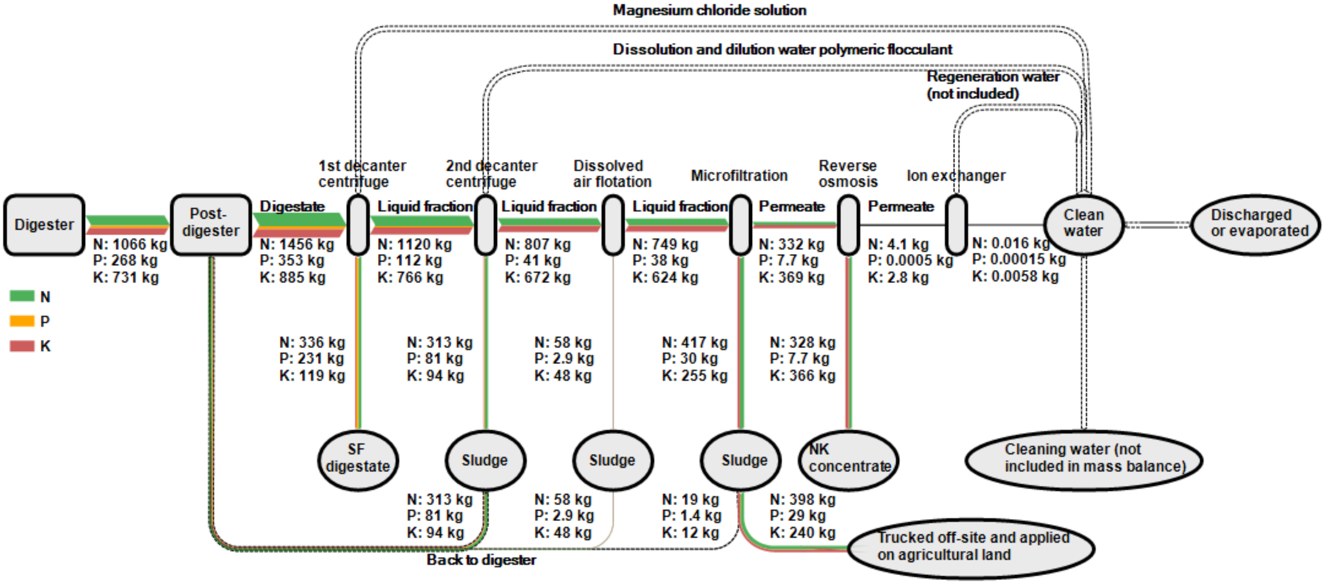


*Figure 4 Total nitrogen (N), phosphorus (P) and total potassium (K) mass flows at Groot Zevert Vergisting for the period October 2019–January 2019. Values are expressed in kilograms per day (kg $d^{-1}$).*

# Groot Zevert Vergisting, Beltrum (Netherlands)

## Monitoring data (energy flow)

Groot Zevert Vergisting produced about 47,837 MWh energy as biogas (Figure 5) of which 68% was sold to a nearby dairy factory of Friesland Campina via a direct 5-km long pipeline. The remaining 32% of the biogas was converted into 5,461 MWh electrical energy by the combined heat and power (CHP) installation. Of this electrical energy 40% was sold via the grid and 60% was used on-site for the biogas plant and GENIUS installation. Only roughly 40% of the thermal energy produced by the CHP can be used on-site due to thermodynamics, amongst others losses in the CHP itself and losses as low temperature exhaust gas.

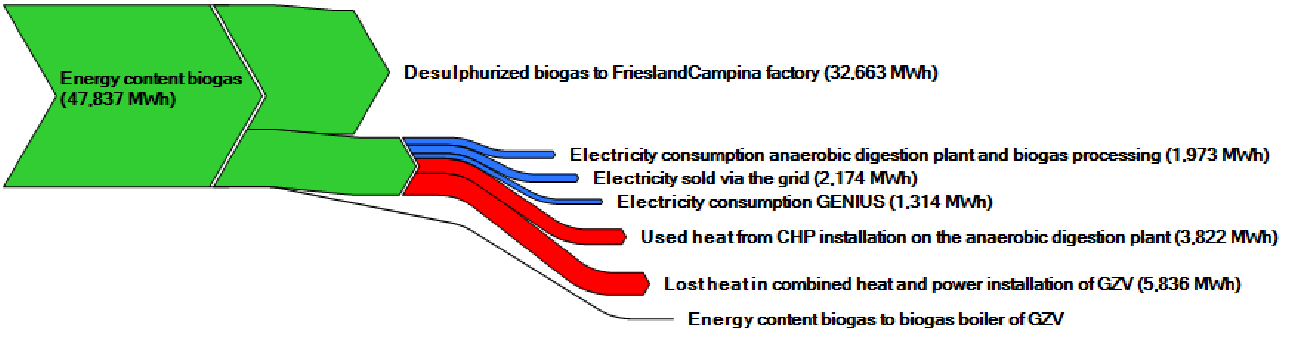


*Figure 5 Energy balance of Groot Zevert Vergisting in 2019.*

## Key Performance Indicators (KPI's)

A KPI is a tool to understand how an organization is performing:

$KPI_1$: EBIT (Earning Before Interest and Tax) margin in % of revenues.
$KPI_2$: EBITA (Earning Before Tax, Interest And Amortization) margin in % of revenues.
$KPI_3$: Substrate Financial Productivity → total revenues per tonne of feedstock.
$KPI_4$: Biogas Financial Productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
$KPI_5$: Digestate Financial Productivity → costs/revenues generated by digestate per tonne of feedstock.

As compared to the other demonstration plants, GZV has a high biogas financial productivity. Processing and disposal of digestate is still costly because GZV does not generate revenues from all produced biobased fertilisers yet.
NK concentrate is blended into Green Meadow Fertiliser (GWM). The farmer to whom the GWM is delivered pays for the amount of N that he is given. From these revenues the storage, transport and application by GZV of the GWM on the farmer's land are paid.

*Table 7. Economic KPI's of the GZV demonstration plant.*

| KPI | |
|---|---|
| EBITA margin | 49% / € |
| EBIT margin | 12% / € |
| Substrate financial productivity | 34.52 € / tonne feedstock |
| Biogas financial productivity | 0.32 € / $m^3$ biogas |
| Digestate financial productivity | -3.63 € / tonne feedstock |

# AM-Power (Pittem, Belgium)

## A short introduction to AM-Power

AM-Power (Figure 1) is located in the western part of Flanders (Belgium), a region with a surplus of animal manure and a high market demand for synthetic fertiliser. This SYSTEMIC demonstration plant is the largest biogas plant in Belgium: it has a treatment capacity of 180 kiloton (kt) feedstock year, spread over four digesters and one post-digester.

*Table 1. Technical information of the biogas plant.*

| Characteristics | |
|---|---|
| Year of construction | 2011 |
| Maximum power output | 7.5 $MW_e$ |
| Digester volume | 20 000 $m^3$ |
| Digestion type | Thermophilic digestion |

## Drivers for Nutrient Recycling

AM-Power has a history of experimenting and investing in the recovery of nutrients. A long time ago AM-Power already envisaged the importance and benefits of moving towards a circular economy. The disposal of digestate is an important cost for biogas plants. On top of this, the agro-food industry in Flanders realizes that their waste streams are valuable and thus demand to be paid by biogas plants to retrieve waste.

*Figure 1. Aerial photo of the demonstration plant AM-Power.*

Competition between biogas plants makes it difficult to get the turnover break even. AM-Power believes that nutrient recovery can be a way to balance this again. AM-Power produces about 160 kt of digestate per year and strives to process this in a cost effective, efficient and relatively simple way, without losing the nutrients. Their technological solution for the recovery of nutrients into valuable fertilisers is currently implemented and currently optimized.

## Feedstocks

In 2019, the co-digestion plant treated 161 kt of feedstock, out of which more than 69% was organic biological waste (industrial food waste and source segregated food waste). Co-substrates mainly include animal manure and glycerine (Table 2). Organic biological waste and animal manure are processed in separate digestion lines.

*Table 2. Origin of AM-Power's digester feedstock (2019).*

| Type | Mass |
|---|---|
| **Organic biological waste** | 111 kt |
| **Manure** | 17 kt |
| **Glycerine and fat-rich substrates** | 9.1 kt |
| **Other feedstock** | 24 kt |
| **Total** | **161 kt** |

## Anaerobic digestion

- Organic waste is collected and homogenized in a mixing unit to a substance with a dry matter (DM) content of approximately 20%.
- Homogenized feedstock is hydrolysed in a separate unit (with a retention time of 3 days) and fed to a thermophilic digester.
- Retention time is around 50–60 days in digesters and 10 days in the post-digester.

Horizon 2020

# AM-Power (Pittem, Belgium)

## Biogas production

In 2019, the biogas produced (including digesters and post-digester) was around 17 $Mm^3$ (Table 3). The biogas is converted by a Combined Heat and Power (CHP) installation into electrical and thermal energy. The calculated amounts of heat and electricity produced in 2019 are respectively 32,486 $MWh_{th}$ and 29,102 $MWh_e$.

*Table 3. Yearly biogas production and average composition before purification (2019).*

| Component | |
|---|---|
| $CH_4$ (%) | 55 |
| $CO_2$ (%) | 45 |
| Total biogas production ($Nm^3$) | 17 Mio |
| Biogas per tonne of feedstock ($m^3$ $t^{-1}$) | 105 |

## Nutrient Recovery Technology

**The previous process worked as follows:**

- Digestate was diluted with liquid fraction of digestate (LF) and sent to two decanter centrifuges for solid/liquid separation. Coagulation and flocculation were favoured by the addition of polymer and iron sulphate. Dilution with recirculated LF was necessary for a better efficiency of the reverse osmosis (RO) step. Each of the two centrifuges requires about 146 kW of electrical energy.
- The phosphorus (P) rich solid fraction of digestate (SF), with a DM content of 24%, was dried in a fluidized bed dryer (268 kW of electricity and 3000 kW of heat). Drying of the SF was accomplished by recycling waste heat from the CHP installation. The exhaust gas from the CHP installations (160 °C) is mixed with ambient air to a temperature of 80 °C. Dry biosolids (containing 2% total-P and 90% DM) were exported to France where P demand is high.
- The nitrogen (N) and potassium (K) rich LF was first processed in a dissolved air flotation unit (DAF), which requires 7 kW of electricity. Iron chloride and polymer were added to reduce the DM content of the LF to 1.2–1.6% DM. Next, the RO unit (100-130 kW) required the addition of sulphuric acid to the influent to ensure a good membrane separation. The resulting concentrate, rich in N and K (respectively 0.5% and 0.4%), was used as a fertiliser on local agricultural land. Permeate water was recycled on site.

**The adjusted process includes a continuous multiple effect vacuum evaporator prior to the RO, thus increasing the recovery of nutrients from digestate (Figure 2).**

- Raw digestate is mechanically separated in the decanter centrifuge. AM-Power is still investigating the optimal polymer dosage for an efficient evaporation step.
- As in the previous process, the solid fraction (25–30% DM) will be dried up to 80–90% DM, while the liquid fraction (3.5–4.5% DM) will be sent to the vacuum evaporator.
- In the evaporator, the vapour will contain ammonia ($NH_3$) that is condensed as ammonia water and subsequently pumped to the RO unit (57 kW). Part of the concentrate that remains after evaporation, which has a DM content of 13%, is blended with the dried biosolids into and organic NPK fertiliser and applied on agricultural land. Compared to the DAF unit, each of the 2 evaporators unit is more energy demanding, consuming respectively about 381 kw of electrical energy and 1500 kW of thermal energy.
- The ammonia containing retentate from the RO is recirculated to the evaporator, while the permeate water is discharged to surface water. The recirculated RO retentate will end up in the concentrated digestate, but it can also be used as a separate product.

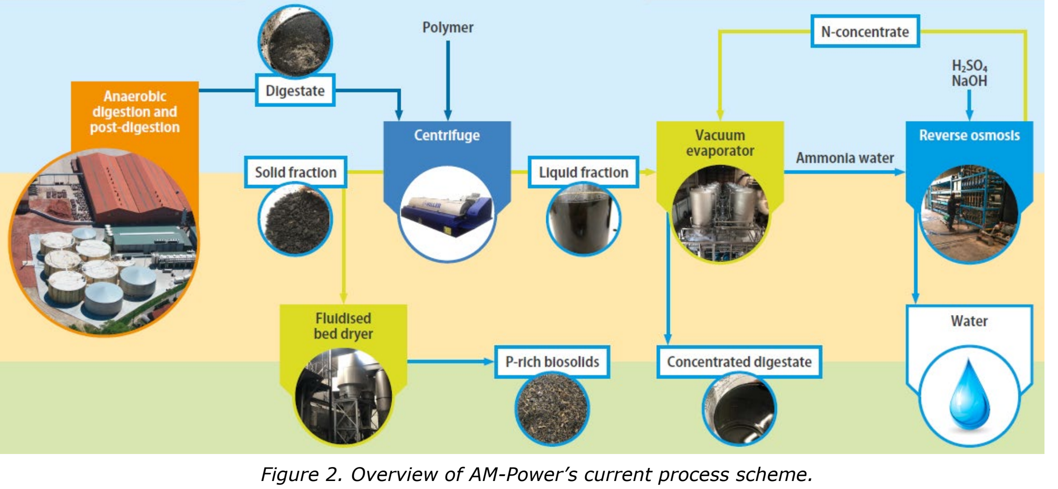


*Figure 2. Overview of AM-Power's current process scheme.*

# AM-Power (Pittem, Belgium)

## Status of construction

The vacuum evaporator consists of two identical units, each with an evaporation capacity of 150 $m^3$ $d^{-1}$. Both evaporator lines have been installed and are in operation (Figure 3). Since the total N content in the permeate water (108 mg $L^{-1}$) did not comply with Flemish discharging limits (15 mg $L^{-1}$), AM-Power decided to introduce an acidification step prior the evaporator to lower the amount of ammonia that evaporates, thereby increasing the amount of N in the concentrate that remains after evaporation.

*Figure 3. Overview of the evaporator.*

Currently, AM-Power is investigating the optimal polymer dosage required for the best performance of the evaporator. The evaporator manufacturer is finalizing some technical aspects of the unit and implements the software for the remote control of the system. The investment of the evaporator and adaptation of the process amounted approximately to 2 M€**.**

## Products and market

- The digestate treated with the DAF and membrane system was processed into P-rich biosolids and mineral concentrate. The mineral concentrate was applied on agricultural land in the region, whereas P-rich biosolids were exported to France.
- With the novel system, AM-Power will blend part of the concentrate that remains after vaporization and P-rich biosolids with a ratio 1:1 into an NPK fertiliser to be exported to nutrient depleted regions. Product characteristics are given in Table 4.

*Table 4. Composition of the recovered products at AM-Power.*

| | Previous process (DAF + RO) | | | Current process (evaporator + RO) | |
|---|---|---|---|---|---|
| | **Digestate** | **NK concentrate** | **P-rich biosolids** | **Concentrate remaining after vaporization** | **P-rich biosolids** |
| pH | 8.6 | 7.6 | 7.5 | 9.6 | 9 |
| Dry Matter (g $kg^{-1}$) | 62 | 24 | 912 | 114 | 840 |
| Organic Matter (g $kg^{-1}$) | 31 | 18 | 523 | n.a. | n.a. |
| N-total (g $kg^{-1}$) | 5.3 | 3.5 | 31 | 4.3 | 17 |
| $NH_4$-N (g $kg^{-1}$) | 3.0 | 3.5 | 0.88 | n.a. | n.a. |
| P-total (g $kg^{-1}$) | 1.3 | 0.02 | 19 | 1.8 | 17 |
| K-total (g $kg^{-1}$) | 3.0 | 3.3 | 11 | 8.9 | 11 |

## Economic benefits

The economic advantages of reusing recovered products are:

- By improving RO efficiency, AM-Power estimated that 160 $m^3$ of water per day will become available as dischargeable water (after polishing by an ion exchanger) or used on site. This amount of water does not have to be transported. About 36 $m^3$ per day of water can be additionally removed by drying the solid fraction digestate.
- Replacement of the DAF by the vacuum evaporator cuts costs for chemical additives.

## Sustainability goals

AM-Power is committed to reach the following targets:

- Reduce $CO_2$ emissions related to digestate transport.
- Reduce the use of polymer usage and eliminate the use of iron salts.
- Increase the production of clean water.

## Monitoring data (total mass and nutrient mass balances)

Total mass (Figure 4) and nutrient mass (Figure 5) balances were calculated for the demonstration plant over the period of one month (February 2020). The aim was to evaluate the overall performance of the plant and the separation efficiencies of each process unit.

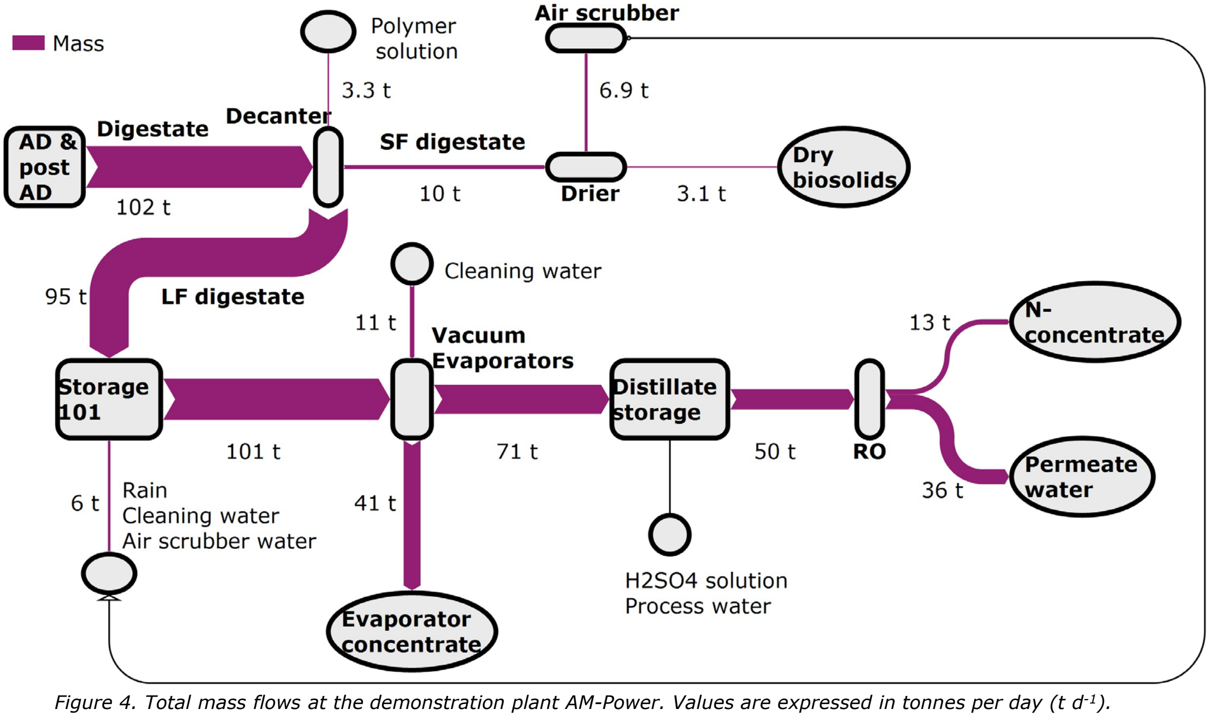


*Figure 4. Total mass flows at the demonstration plant AM-Power. Values are expressed in tonnes per day (t d-1).*

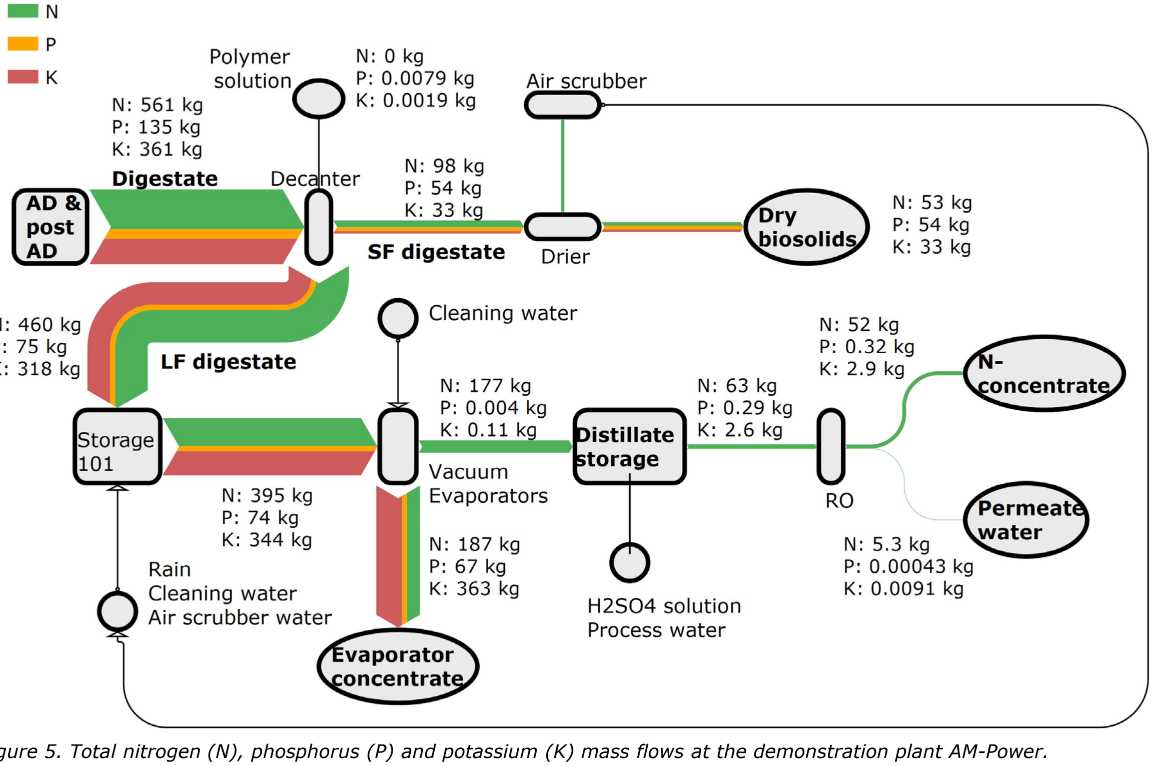


*Figure 5. Total nitrogen (N), phosphorus (P) and potassium (K) mass flows at the demonstration plant AM-Power. Values are expressed in kilograms per day (kg d-1).*

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# AM-Power (Pittem, Belgium)

## Monitoring data (energy balance)

In terms of energy production, in 2019 the plant generated 44,177 MWh of thermal energy. The CHP installation also generated 32,295 MWh of electricity, out of which 9% was consumed at AM-Power and the rest was sent to the national grid (Figure 6).

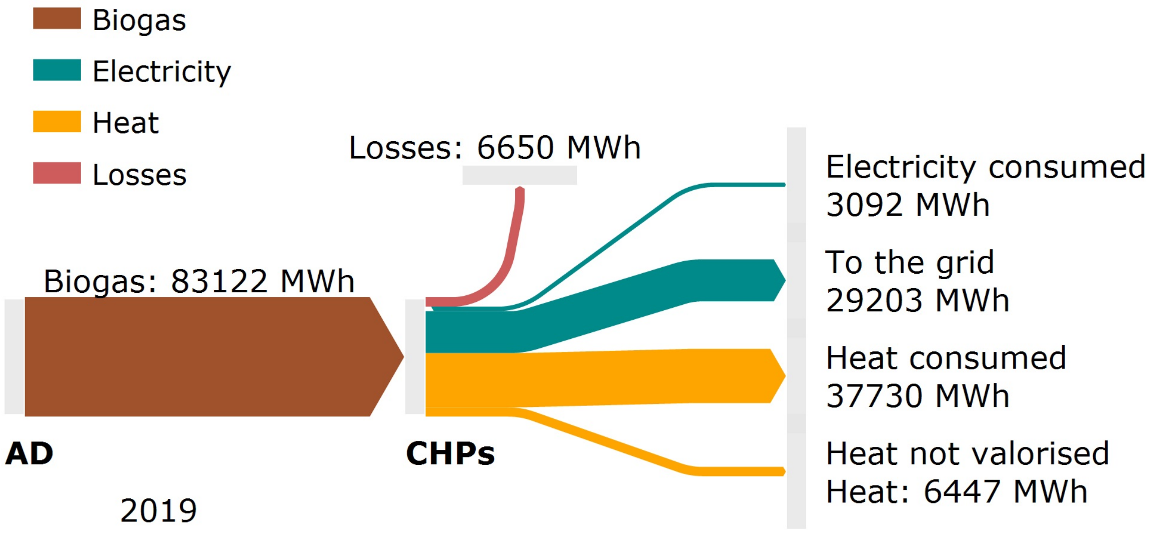


*Figure 6. Energy balance of the demonstration plant AM-Power.*

## Key Performance Indicators (KPI's)

A KPI is a tool to understand how an organization is performing:

$KPI_1$: EBIT (Earning Before Interest and Tax) margin in % of revenues.
$KPI_2$: EBITA (Earning Before Tax, Interest And Amortization) margin in % of revenues.
$KPI_3$: Substrate Financial Productivity → total revenues per tonne of feedstock.
$KPI_4$: Biogas Financial Productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
$KPI_5$: Digestate Financial Productivity → costs/revenues generated by digestate per tonne of feedstock.

*Table 7. KPI's of AM-Power's demonstration plant.*

| KPI | |
|---|---|
| EBITA margin | 25% / € |
| EBIT margin | 3% / € |
| Substrate productivity | 44 € / tonne feedstock |
| Biogas productivity | 0.24 € / m³ biogas |
| Digestate productivity | - 7.2 € / tonne feedstock |

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# Acqua&Sole, Vellezzo Bellini (Italy)

## A short introduction to Acqua&Sole

The biogas plant of Acqua&Sole (Figure 1) is located in Vellezzo Bellini (Northern Italy), in an area dedicated to cereal cultivation, mainly rice. Acqua&Sole has a focus on nutrient recycling with special attention to the development of a system for digestate application to agricultural lands (direct injection into the soil). This system is developed in collaboration with local farmers.

*Table 1. Technical information of the biogas plant.*

| **Characteristics** | |
|---|---|
| Year of construction | 2016 |
| Maximum power output | 1.6 ($MW_e$) |
| Digester volume | 13 500 ($m^3$) |
| Digestion type | Thermophilic digestion |

The aims of the system are to maximize fertilisation and minimize ammonia ($NH_3$) and odour emissions. In addition to the production of a soil improver (digestate), the demonstration plant produces ammonium sulphate from recovered $NH_3$ by nitrogen (N) stripping during the anaerobic digestion (AD) step. This ammonium sulphate is used as N fertiliser. For the recovery and reuse of nutrients, Acqua&Sole has an ambition of improving soil fertility without any use of synthetic fertiliser over an area of 5,000 hectares. Also Acqua&Sole wants to deliver the nutrients required for the surrounding farms.

## Drivers for nutrient recycling

Degradation of N-rich feedstock leads to the formation of $NH_3$ which can have an inhibiting effect on anaerobic methanogenic microorganisms when reaching toxic levels are reached. Stripping of N and its subsequent recovery as ammonium sulphate is a great opportunity to prevent inhibition of the anaerobic digestion process. Furthermore, low carbon content in soils is an issue in Italy and the utilization of soil improvers (i.e. digestate) is a valuable tool to tackle this. However, restrictions on N application on agricultural land limit their use of organic materials, making it necessary to find solutions to lower the N content of the produced digestate.

*Figure 1. Aerial photo of the demonstration plant Acqua&Sole.*

## Feedstocks

The co-digestion capacity is 120 kiloton (kt) organic feedstock per year. In 2019, 82 kt feedstock was digested of which about 85% was sewage sludge and 15% was digestate from anaerobic treatment of source-segregated domestic food waste (SSFW), and agro-food waste (Table 2). Liquid fraction of SSFW was not fed to the digester in 2019. The plant can digest manure, expired food, organic wastes, sewage sludge and agro-food industry waste.

*Table 2. Origin of Acqua&Sole's digester feedstock (2019).*

| Type | Origin | Mass |
|---|---|---|
| **Sewage sludge** | Wastewater treatment plants | 69.2 kt |
| **Co-substrates** | Digestate from anaerobic treatment of source-segregated domestic food waste | 5.4 kt |
| | Agro-food waste | 7.2 kt |
| **Total** | | 81.8 kt |

acqua & sole

Horizon 2020

# Acqua&Sole, Vellezzo Bellini (Italy)

## Biogas production

Anaerobic digestion is performed in three consecutive digesters with a volume of 4,500 $m^3$ each. The biogas produced by the plant (Table 3) is converted by a Combined Heat and Power (CHP) installation into electrical energy and heat.

*Table 3. Biogas production and average composition before purification in 2019.*

| Component | |
|---|---|
| $CH_4$ (%) | 60 - 65 |
| $CO_2$ (%) | 33 - 36 |
| $H_2S$ ppm | <10 ppm |
| $O_2$ (%) | <1 |
| Total biogas production ($Nm^3$) | 3.3 Mio |
| Specific $CH_4$ production ($Nm^3$ $CH_4$ $t^{-1}$ OM) | 198 |

*Figure 2. Digestate injection application on fields.*

## Digestate characteristics

- Thermophilic digestion ensures a better control of pathogenic and intestinal microorganisms in the digestate.
- The high N/$NH_4$-N ratio of the digestate favours long-term fertilisation.
- Uniformity of digestate distribution is ensured by the digestate injection application system (Figure 2).

## Nutrient Recovery and Reuse (NRR) technology

From April 2016 onwards, the plant operates as follows (Figure 3):

- Feedstock (organic waste) is collected in basins located in a closed building to prevent the release of odour. A bio-filter placed on the roof of the building purifies the exhaust air;
- Organic waste is moved to a mixing unit where it is heated and homogenized with biomass coming from the third digester;
- Homogenized and inoculated feedstock is fed to the thermophilic process (minimum retention time of 20 days and temperature of 55 °C) which ensures full hygienization of the incoming sludge;
- The process is equipped with a side-stream N stripping unit, whereby biogas acts as stripping agent, $NH_3$ is extracted by leading biogas through sulphuric acid (about 50%) resulting in an ammonium sulphate solution;
- Both the digestate and the ammonium sulphate solution are stored in steel tanks.

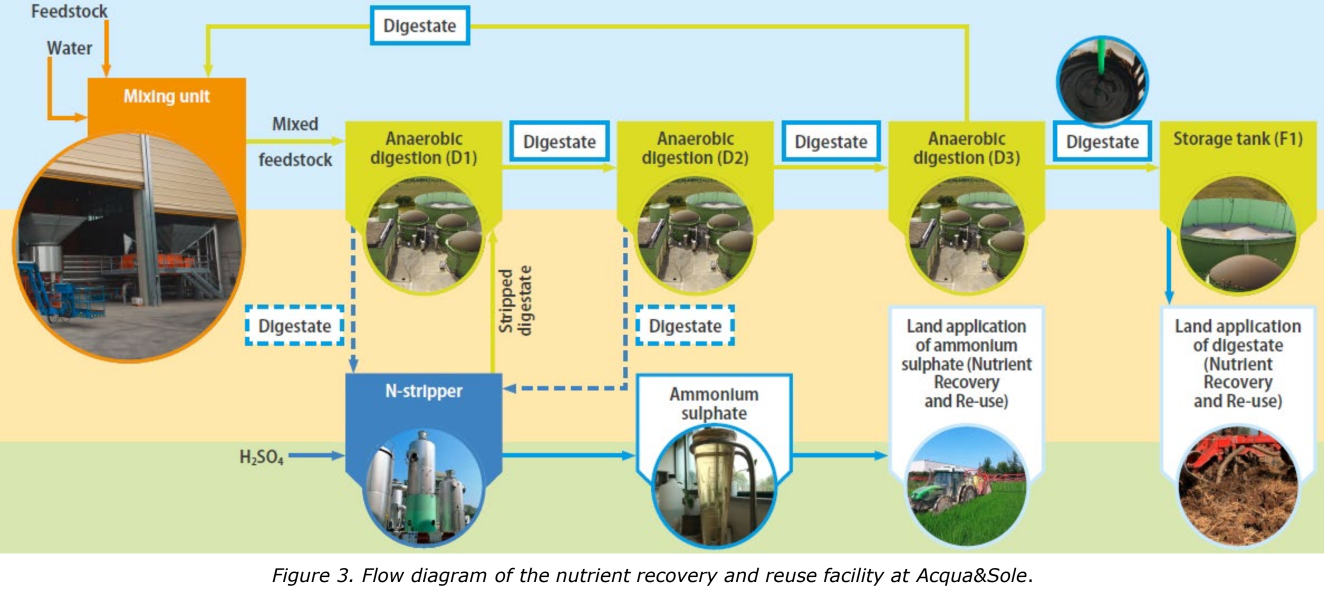


*Figure 3. Flow diagram of the nutrient recovery and reuse facility at Acqua&Sole.*

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Circular solutions for biowaste

# Acqua&Sole, Vellezzo Bellini (Italy)

## Status of construction

The construction of a novel N absorber was completed by the end of 2019. The start-up of the new absorption unit was coordinated by switching off the existing unit and took place in January 2020 (this transitional period had to be as short as possible in order to avoid $NH_3$ inhibition in the digester). Currently, Acqua&Sole is fine-tuning the operational conditions, and up to now 27% of $NH_3$ removal is achieved. This is 35% higher than with the previous absorber unit which could remove about 20% of $NH_3$.

## Products and market

The annual maximum capacity of the co-digestion plant is about 120 kt of organic waste, which will be mixed with water and transformed into at maximum 192 kt of digestate. Product characteristics are given in Table 4.
Acqua&Sole estimated that the use of digestate could replace the following amount of synthetic fertilisers per year: 1550 t N, 1160 t $P_2O_5$ and 170 t $K_2O$.

*Table 4. Composition of the recovered products at Acqua&Sole (average data January 2018 – October 2019, n=17).*

| | Digestate | Ammonium sulphate |
|---|---|---|
| Dry matter (g kg$^{-1}$) | 102 | 354 |
| Organic matter (g kg$^{-1}$) | 62 | <1.6 (TOC) |
| N-total (g kg$^{-1}$) | 8.0 | 73 |
| P-total (g kg$^{-1}$) | 3.0 | 0.010 |
| K-total (g kg$^{-1}$) | 0.65 | 0.010 |

## Economic benefits

Acqua&Sole calculated that the replacement of conventional fertiliser with digestate over a surface area of 5,000 hectares generated savings of about 2.3 million € per year (Table 5), but Acqua&Sole does not have direct savings from chemical fertiliser replacement. The implementation of the N absorber will further reduce the N content in the digestate, and as such allows a higher amount of digestate to be distributed on fields.

*Table 5. Saved economic costs.*

| Conventional fertiliser | Cost € t$^{-1}$ * | Quantity t y$^{-1}$ | Total (€) |
|---|---|---|---|
| Urea 46% N | 344 | 3 370 | 1 159 280 |
| triple superphosphate 46% $P_2O_5$ | 369 | 2 520 | 929 880 |
| Potash 60% $K_2O$ | 669 | 280 | 187 320 |
| **Total Saved Cost** | | | **2 276 480** |

* Source: CCIAA Modena, Average 2017

This will allow distribution of a higher amount of digestate per hectare with benefits in terms of transport and disposal costs. On top of that, lowering the $NH_3$ content in the digester will optimize the digestion process, by avoiding toxicity effects on methanogenic microorganisms and it increases the ammonium sulphate solution production.

## Sustainability goals

Acqua&Sole is committed to reach the following targets:

- Close nutrient cycles through the use of fertilisers produced from sewage sludge and biowaste.
- Showcase that fertilisers from sewage sludge and biowaste are agronomically effective and environmentally friendly.
- Increase soil quality due to the use of digestate rather than chemical fertiliser, thereby contributing to sequestration of carbon in soil.
- Reduce $NH_3$, $NO_3$ and $N_2O$ emissions during digestate application.
- Eliminate unpleasant odour to improve public acceptance.

## Monitoring data (total mass and nutrient mass balances)

Total mass (Figure 4) and nutrient mass (Figure 5) balances were calculated for the demonstration plant over a period of 280 days, from January 2019 to October 2019. The aim was to evaluate the overall performance of the plant, including the recovery efficiencies of the N stripper. In the N stripper, 8.7% of total nitrogen (TN) fed to the system was collected as ammonium sulphate solution (which has an $NH_4$-N content of 73 g $kg^{-1}$).

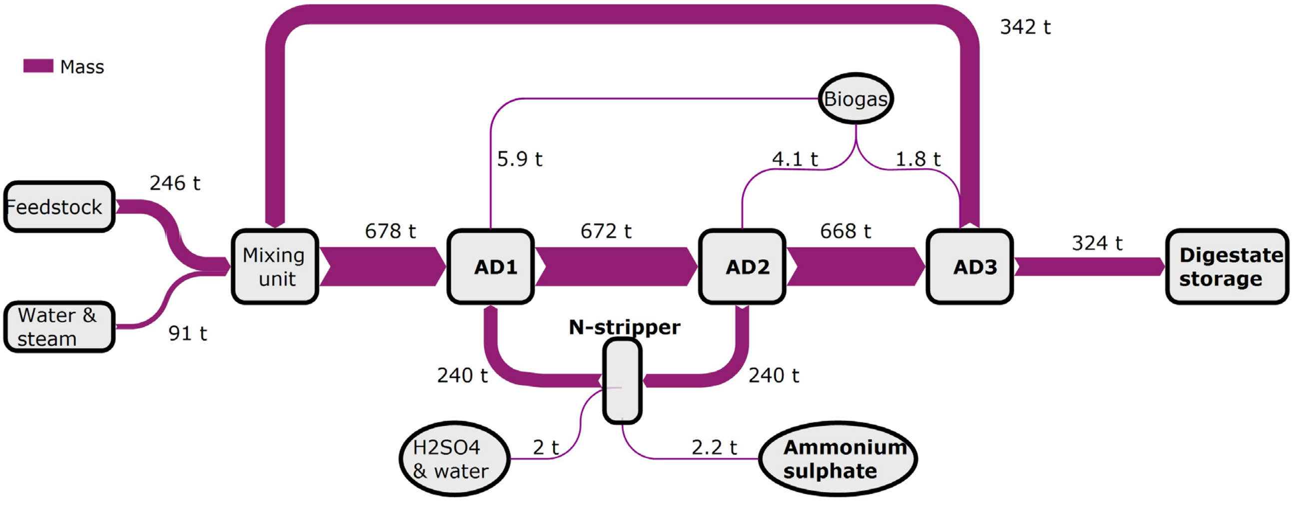


*Figure 4. Total mass flows at the demonstration plant Acqua&Sole. Values are expressed in tonnes per day (t $d^{-1}$).*

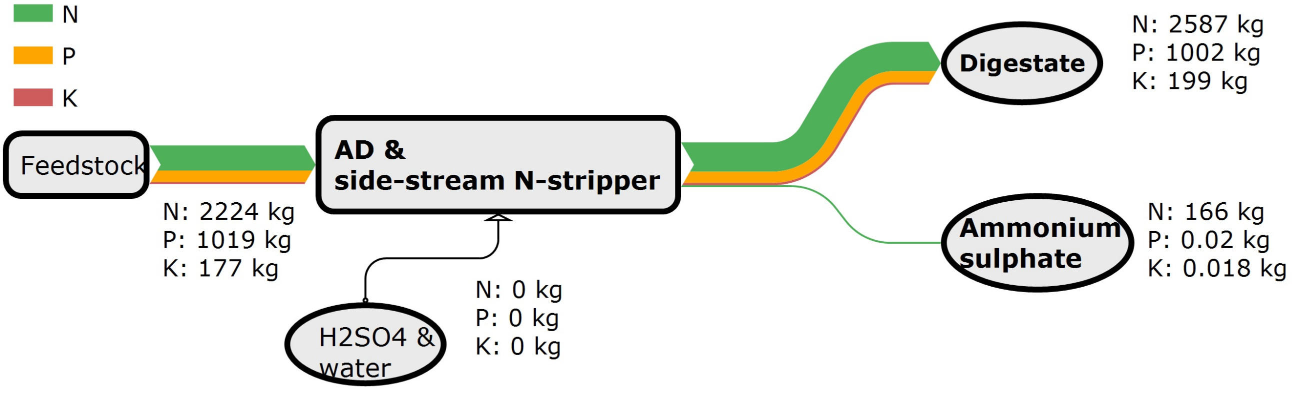


*Figure 5. Total nitrogen (N), phosphorus (P) and potassium (K) mass flows at the demonstration plant Acqua&Sole. Values are expressed in kilograms per day (kg $d^{-1}$).*

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# Acqua&Sole, Vellezzo Bellini (Italy)

## Monitoring data (energy balance)

A preliminary energy balance was drafted for the period January–October 2019 and it will be implemented in the near future.
In terms of energy production, the plant generated 4,780 MWh of thermal energy, which was entirely used at the installation. An additional 1,343 MWh of thermal energy were required to fulfil the heating requirements of the plant. The CHP installation also generated 6,632 MWh of electricity, out of which 4.5% was consumed by the N stripper (Figure 6).

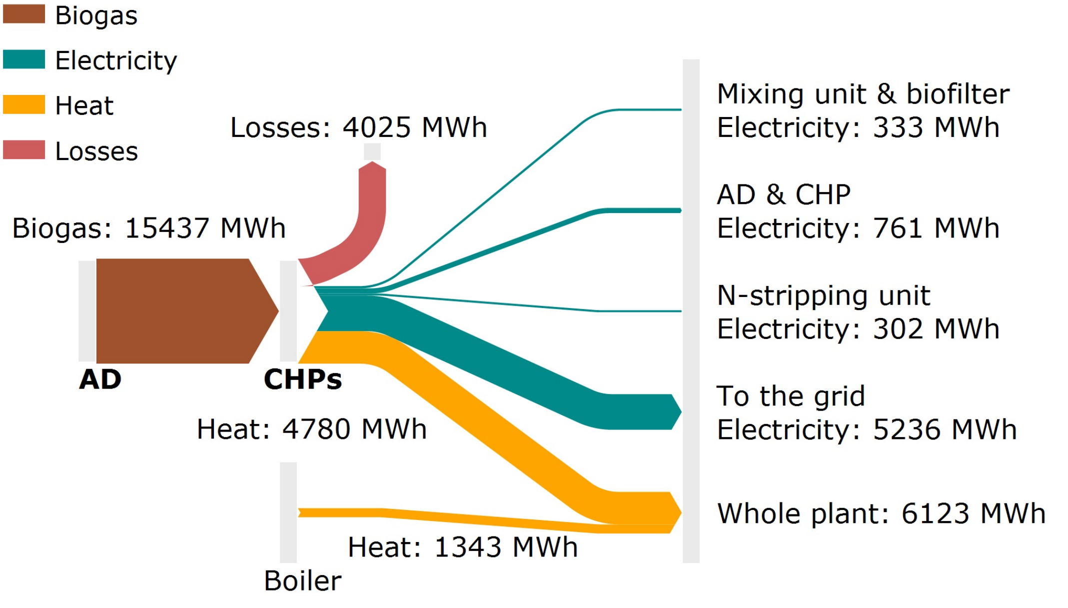


*Figure 6. Energy balance at the demonstration plant Acqua&Sole.*

## Key Performance Indicators (KPI's)

A KPI is a tool to understand how an organization is performing:

$KPI_1$: EBIT (Earning Before Interest and Tax) margin in % of revenues.
$KPI_2$: EBITA (Earning Before Tax, Interest And Amortization) margin in % of revenues.
$KPI_3$: Substrate Financial Productivity → total revenues per tonne of feedstock.
$KPI_4$: Biogas Financial Productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
$KPI_5$: Digestate Financial Productivity → costs/revenues generated by digestate per tonne of feedstock.

*Table 7. KPIs of Acqua&Sole's demonstration plant.*

| KPI | |
|---|---|
| EBITA margin | 41% / € |
| EBIT margin | 16% / € |
| Substrate productivity | 57 € / tonne feedstock |
| Biogas productivity | 0.34 € / $m^3$ biogas |
| Digestate productivity | -4.6 € / tonne feedstock |

# Benas-GNS, Ottersberg (Germany)

## A short introduction to Benas

The SYSTEMIC demonstration plant of Benas (Figure 1) is located in North Germany, near Bremen. The plant has a process capacity 174 kilotonnes (kt) feedstock per year distributed over four digesters and three storage tanks. Benas also owns 3,500 hectares of arable land (1,000 ha near Ottersberg), has 35 employers and its own truck fleet.

*Table 1. Technical information of the biogas plant.*

| Characteristics | |
|---|---|
| Year of construction | 2006 |
| Maximum power output | 11.3 ($MW_e$) |
| Digester volume | 39 100 ($m^3$) |
| Digestion type | Thermophilic digestion |

## Drivers for nutrient recycling

Chicken manure is readily available in the region as a feedstock for biogas plants at a relative low price to be paid to the farmers. Nevertheless, due to ammonia ($NH_3$) inhibition of the anaerobic microorganism, it remains a difficult stream to digest. Restrictions on nitrogen (N) application on agricultural land make it hard to dispose it. This leads to high transportation cost due to large transport distances. Benas, produces up to 400 t $d^{-1}$ of digestate.

*Figure 1. Aerial photo of the demonstration plant Benas.*

Benas therefore has been forced to search for a digestate treatment technology that lowers the $NH_3$ content of the digestate, recovers N and reduces the amount of digestate for field application. The plant director owns arable land, 200 km from the Ottersberg, which is fertilised with nutrients recovered at Benas installation. Trucks bring fertilisers to these agricultural fields and drive back to Ottersberg with crops that are used as feedstock for the digester. Benas now already benefits from investments in nutrient recovery techniques: less use of mineral fertiliser on their own lands, lower production costs due to the use of gypsum for recovering $NH_3$, income from selling the recovered biogas fibers.

## Feedstocks

The co-digestion capacity is 174 kt feedstock (organic substrate) per year. In 2019, the co-digestion plant digested about 92 kt substrate, out of which 85% was crop material and 15% was animal manure (Table 2).

*Table 2. Origin of Benas' digester feedstock (2019).*

| Type | Mass |
|---|---|
| **Maize silage** | 41 kt |
| **Other crops** | 37.9 kt |
| **Chicken manure** | 13.3 kt |
| **Total** | **92.2 kt** |

*Table 3. Yearly biogas production (2019) and average composition before purification.*

| Component | |
|---|---|
| $CH_4$ (%) | 53 |
| $CO_2$ (%) | 46 |
| $H_2S$ (ppm) | 83 |
| $O_2$ (%) | 0.1 |
| Total biogas production ($Nm^3$) | 20.4 Mio |
| Biogas per tonne of feedstock ($m^3$ $t^{-1}$) | 222 |

## Biogas production

The biogas produced in 2019 was around 20 mio $Nm^3$ (Table 3). About 12 mio $Nm^3$ were combusted by the Combined Heat and Power (CHP) installation into electrical (27,993 MWh) and thermal (25,518 MWh) energy. On average 8 mio $Nm^3$ were upgraded to biomethane, which corresponds to an energy production of 37,699 MWh.

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# Benas-GNS, Ottersberg (Germany)

## Nutrient Recovery & Reuse (NRR) technology

After being stored in post-digesters, the digestate undergoes a separation step, resulting in a liquid and solid fraction which both can be applied directly on agricultural land. Also a second approach is possible: an internal recycle of digestate is used as a substrate for the FiberPlus plant, for removing $NH_3$ (detailed description below). In this approach, $NH_3$ and carbon dioxide are brought into contact with gypsum to form ammonium sulphate and calcium carbonate (Figure 2).

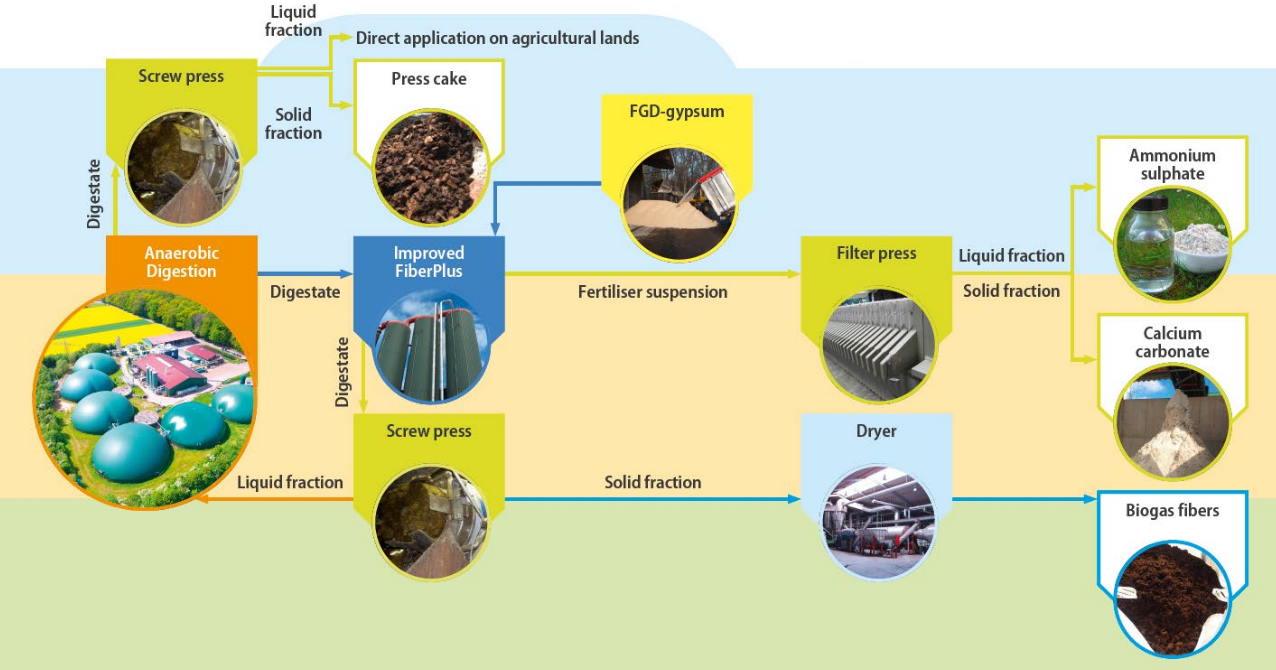


*Figure 2. Current NRR facility at demonstration plant Benas.*

## Modified stripping process for N removal (FiberPlus process)

In 2003, GNS developed and patented the FiberPlus process in which $NH_3$ is stripped from digestate without the use of acids, bases or external stripping media (Table 4). The process requires the addition of Flue Gas Desulphurisation-gypsum (FGD-gypsum) to produce two marketable fertilisers: ammonium sulphate solution (22–26%) and solid calcium carbonate (75% dry matter). Moreover, the process does not require any external heat source and relies solely on the exhaust heat from the CHP installation. On average it consumes 100 kWh of electrical energy per $m^3$ of digestate processed. The gypsum used for the process comes from the FGD system of coal fired power plants.

From 2007/2008 this type of N stripper was installed at Benas and from 2011 the plant recycles N-depleted digestate back to the digester. There are several advantages of the described system:

- The plant recovers 56–85% of $NH_3$ contained in the digestate, which is approximately 200 tonnes per year;
- $NH_3$ inhibition is prevented, increasing the biogas yield by 8%;
- Since October 2016 the process has been further implemented for the production of $NH_3$-free fibers suitable for different applications in the fibre and timber industries (i.e. fibreboard).

*Table 4. Technical specification of the modified stripping process.*

| Technical information | |
|---|---|
| Digestate input | 5–25 $m^3$ $h^{-1}$ |
| $NH_3$ input | 3–5 g $L^{-1}$ |
| Dry Matter content of input | 5–12.5 % |
| Striping efficiency | 56–85% |
| Ammonium sulphate output | 5–40 t $d^{-1}$ |
| Calcium carbonate output | 1.5–14 t $d^{-1}$ |

# Benas-GNS, Ottersberg (Germany)

## Status of construction

In order to make the electricity production more flexible, Benas has completed the construction of an additional biogas storage tank. Two additional CHP installations have been installed and all digesters have been fitted with new roofs.

## Products and market

In 2019, Benas generated 1,128 t of calcium carbonate, 3,545 t of ammonium sulphate and <1 000 t of biogas fibres. Product characteristics are given in Table 5.

The ammonium sulphate solution is recommended by GNS as a good fertiliser for several reasons:

- neutral pH is well tolerated by plants;
- concentration of 22–26% dry matter (DM) avoids evaporative crystallization, making it suitable for direct application on crops;
- can be used for producing mineral fertiliser solutions or for upgrading manure or digestate low in N content.

Also, the use of calcium carbonate has multiple advantages:

- calcium is an important plant nutrient;
- increases soil pH and enhances nutrient availability without causing alkalinisation because it dissolves only in acid soils;
- improves soil structure and biological activity.

*Table 5. Composition of the recovered products at Benas (average data February 2018–February 2020).*

| | Digestate | Liquid fraction digestate | Solid fraction digestate | Calcium carbonate | Ammonium sulphate |
|---|---|---|---|---|---|
| Dry matter (g kg$^{-1}$) | 105 | 94 | 248 | 690 | 221 |
| Organic matter (g kg$^{-1}$) | 83 | 68 | 222 | 29 | 0.35 (TOC) |
| N-total (g kg$^{-1}$) | 7.4 | 7.2 | 7.9 | 13 | 45 |
| P-total (g kg$^{-1}$) | 1.9 | 1.6 | 1.8 | 0.17 | 0.0027 |
| K-total (g kg$^{-1}$) | 6.8 | 6.4 | 8.9 | 0.4 | 0.0059 |

## Economic benefits

GNS calculated that the replacement of conventional fertiliser with ammonium sulphate and calcium carbonate would generate a savings of about 300, 000 € per year (Table 6). In addition, the sale of fibres is estimated to generate around 82,000 € per year. The implementation of the N stripper, will reduce the N content of the digestate, by-passing restrictions on N application rates.

*Table 6. Saved economic costs.*

| Saved cost | € y$^{-1}$ |
|---|---|
| Use of ammonium sulphate solution | 244,000 |
| Use of calcium carbonate | 63,000 |
| Income from fibres | 82,000 |
| **Total savings** | **389,000** |

Additional sources of income may be represented by:

- Digestate recycling after stripping and consequent higher biogas yield;
- Increase the amount of chicken manure digested as it is a relatively cheap feedstock;
- More efficient heat utilization.

## Sustainability goals

Benas is committed to reach the following targets:

- Decrease green house gas (GHG) emissions by lowering $CO_2$ emissions from digestate transportation;
- Reuse nutrients in the form of ammonium sulphate and calcium carbonate on their own fields;
- Production of low-N fibres as a sustainable alternative for wood fibres or peat.

## Monitoring data (total mass and nutrient mass flows)

Total mass (Figure 3) and nutrient mass (Figure 4) balances were calculated for the demonstration plant for a period of four months, January 2019 until April 2019. The aim was to evaluate the overall performance of the plant and the recovery efficiency of the N stripper. Results indicate that 31% of total N contained in the digestate that is processed in the N stripper was recovered as ammonium sulphate and 4.5% of total N as calcium carbonate. This translates into an $NH_4$-N recovery efficiency from digestate of about 57% as ammonium sulphate and 7.8% as calcium carbonate.

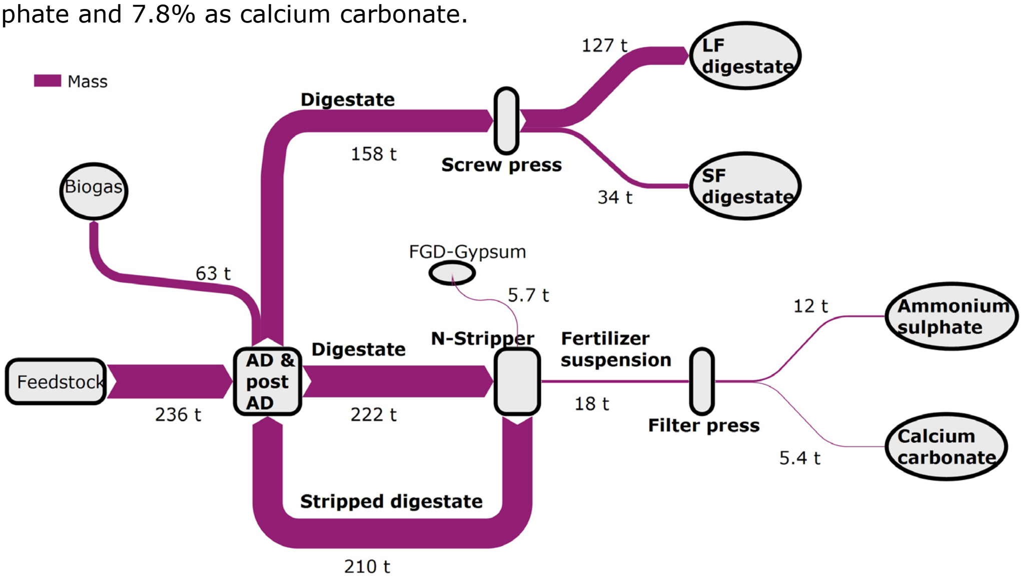


*Figure 3. Total mass flows at the demonstration plant Benas. Values are expressed in tonnes per day (t d-1).*

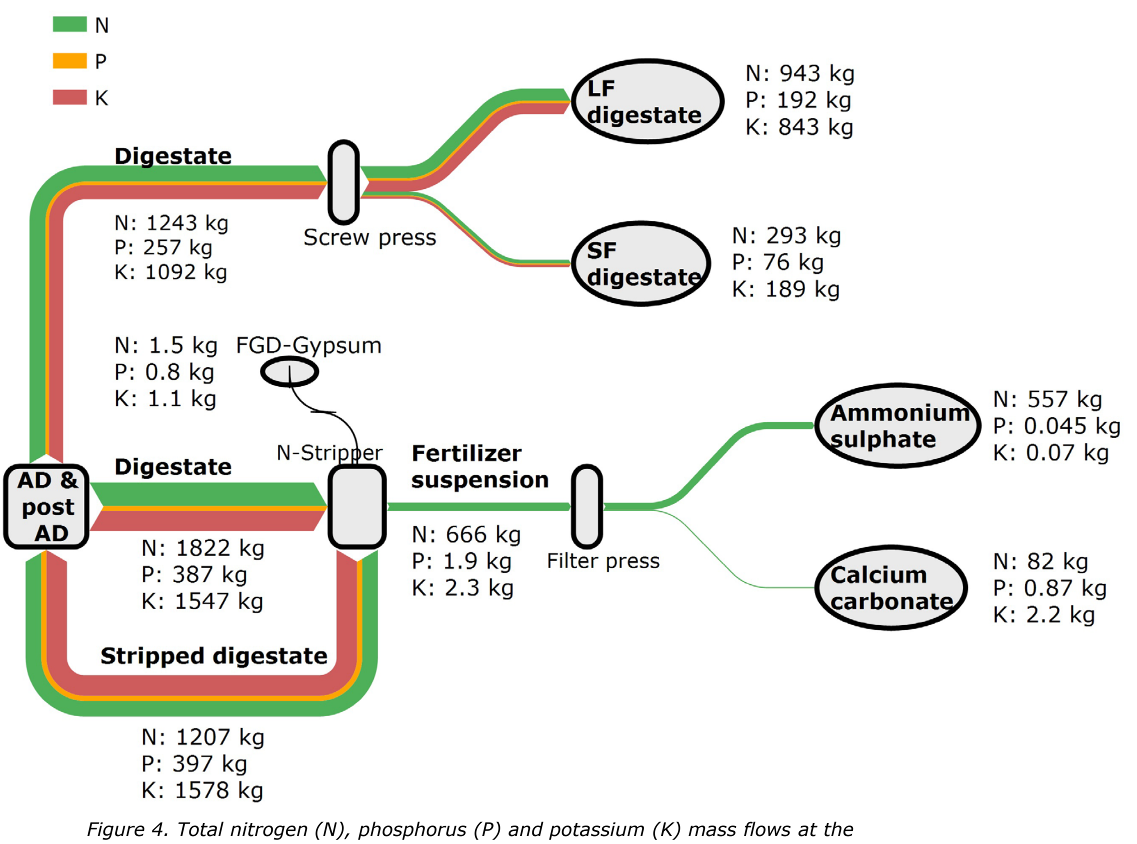


*Figure 4. Total nitrogen (N), phosphorus (P) and potassium (K) mass flows at the demonstration plant Benas. Values are expressed in kilograms per day (kg d-1).*

# Benas-GNS, Ottersberg (Germany)

## Monitoring data (energy flow)

In terms of energy production, the plant generated 25,518 MWh of thermal energy, out of which 21% is consumed by the N stripper. The remainder is used for cooling of the stripping gas and biogas, heating the digesters, drying of wood and corn silage and heating of rooms in the building. The CHP installation generates 27,993 MWh of electricity: less than 3% of this is used for the operation of the N stripper, the rest is sent to the national grid (Figure 5).

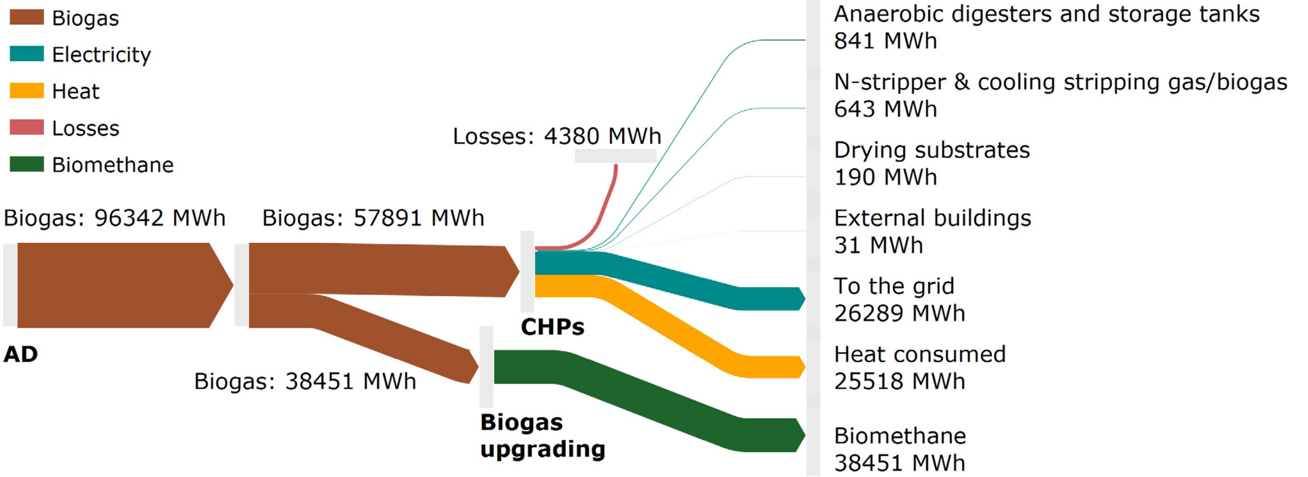


*Figure 5. Energy balance of the demonstration plant Benas in 2009.*

## Key Performance Indicators (KPI's)

A KPI is a tool to understand how an organization is performing:

$KPI_1$: EBIT (Earning Before Interest and Tax) margin in % of revenues.
$KPI_2$: EBITA (Earning Before Tax, Interest And Amortization) margin in % of revenues.
$KPI_3$: Substrate Financial Productivity → total revenues per tonne of feedstock.
$KPI_4$: Biogas Financial Productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
$KPI_5$: Digestate Financial Productivity → costs/revenues generated by digestate per tonne of feedstock.

*Table 7. Economic KPIs of Benas' demonstration plant.*

| KPI | |
|---|---|
| EBITA margin | 36% / € |
| EBIT margin | 13% / € |
| Substrate financial productivity | 80 € / tonne feedstock |
| Biogas financial productivity | 0.38 € / m³ biogas |
| Digestate financial productivity | -0.95 € / tonne feedstock |